University of Maine

Maine Agricultural Experiment Station

ORONO

BULLETIN 316 JANUARY, 1924

THE IMPORTANCE AND NATURAL SPREAD OF POTATO DEGENERATION DISEASES.

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BULLETIN 316

THE IMPORTANCE AND NATURAL SPREAD OF POTATO DEGENERATION DISEASES.[1]

DONALD FOLSOM and E. S. SCHULTZ.[2]

SUMMARY

(1) Maine conditions are relatively unfavorable for the development and spread of degeneration diseases or for a great reduction of yield rate by them. Nevertheless such diseases cause more degeneration or "running-out" of potatoes in Maine than is necessary or desirable. They are represented here chiefly by mosaic, leafroll, and spindle-tuber.

(2) Tests of the effects of spindle-tuber upon Green Mountains and Irish Cobblers and of mild mosaic upon Green Mountains were made in 1923 with two or more plots of any diseased or healthy part of a strain. The yield rate was reduced to the extent of from 20 to 40 per cent. Differences due to disease were much more significant than differences due to strain or origin.

(3) Healthy stocks are often planted next to diseased fields. Aphids can transmit disease. In 1922, thirty-five fields were sampled in a study of the amount and distance of spread of mosaic and spindle-tuber from diseased to healthy fields. The samples, grown in 1923, showed that in 1922 one or both diseases had spread, in some places having done so enough to infect half the plants in the first five healthy rows next to diseased rows, and in other places spreading across the healthy field as far as the fortieth or fiftieth row.[3] Hill-to-hill spread in a partly diseased field was also found to be common. On the other hand,

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[1]This bulletin contains results of investigations conducted as a cooperative project by the Department of Plant Pathology of the Maine Agricultural Experiment Station and the Office of Cotton, Truck and Forage Crop Disease Investigations of the Bureau of Plant Industry of the U. S. Department of Agriculture. The publication as a Station bulletin and the arrangement of the authors' names are not intended to indicate that one cooperating institution contributed more than the other to the results.

[2]Plant Pathologist, U. S. Department of Agriculture.

[3]Rows here are usually a little less than three feet apart, that is, from middle to middle.

in some places isolated healthy fields and even healthy fields grown next to diseased stocks, remained mostly or wholly as healthy as before. Some data are presented regarding the spread of mosaic compared with the spread of spindle-tuber, the direction of spread, the results of growing parts of the same strain in different places, the harboring of mosaic by Irish Cobblers, the partial infection of tubers, and the abundance of aphids.

(4) In many apparently good fields, at least 10 per cent of the possible gross yield is lost through degeneration diseases. Therefore if planted instead with healthy seed, only nine-tenths of the acreage in such cases would be required to produce the same amount of crop.

(5) Losses from degeneration or "running-out" can be avoided more than it has in the past by giving due consideration, when selecting seed, to the presence of degeneration diseases in the field and to the probability of their spread and increase.

INTRODUCTION

It is well known that yield rates of potatoes are high in Maine and that Maine potatoes have been highly valued for seed purposes in other states. The writers have conducted experiments which indicate that Maine conditions, especially in the northeastern part of the state, often are relatively unfavorable for the development and spread of degeneration diseases. However, in spite of these advantages, the high expense associated with potato growing in Maine makes it highly desirable for everything possible to be done to increase the yield rate and profit per acre, or, conversely, to decrease the acreage required to produce a given yield and profit.

The running-out or degeneration of potatoes, while worse in many other regions, is too frequently evident in Maine. Seed stock that has looked good in the bin or even in the field as growing vines, often produces dwarfed, low-yielding and low-quality crops in spite of favorable growing conditions. Growing conditions in Maine normally result in the production, from degenerate stocks, of yields that would be considered large for healthy stocks in many places elsewhere, but the higher yield rates of healthy stocks in Maine show that some undesirable elements are frequently not under control.

Experiments and observations carried on by the writers, chiefly in Maine, and by others in the United States, Canada, Ireland, England, France, Holland, Germany, and Japan, show that the degeneration of potatoes is not due directly to temperature, soil, fertilizer, and other environmental conditions, as was long considered true, but is largely due to disease. That is, degeneration is capable of spreading from one hill to another, from one row to another, and from one field to another. The more common types of degeneration diseases, in Maine at least, are mosaic, leafroll, and spindle-tuber.[4] The cause of any degeneration disease is not known yet, although it is evidently contained in the juice or sap as transferred from diseased to healthy plants in certain experiments.

Effect of Degeneration Diseases Upon the Yield Rate in 1923.

Preceding reports by the writers[5] have shown that mosaic, leafroll, and spindle-tuber reduce the yield rate even in northeastern Maine where favorable conditions often permit diseased plants to produce a high yield. These reports were based upon a comparison of plots or of smaller groups of hills grown without duplication. Each comparison was made of two or more parts of the same strain, that is, of a stock with a single known origin. Often the healthy part of a strain was rogued of diseased plants, a procedure which may have affected the yield rate in a way somewhat hard to determine.

In 1921 it was seen that from the standpoint of accuracy, the methods previously used should not be followed further, and that they could not be followed with the same lots because of the increase of spindle-tuber, incapable of being rogued from machine-planted lots. Consequently in 1922 preparations were

[4]These three diseases are described and discussed by Donald Folsom in Maine Station Bulletins 292, 297, and 312, respectively.

[5]Folsom, Donald. Potato mosaic. Maine Agric. Exp. Sta. Bul. 292. p. 157-184. 1920. See p. 161-162.....Potato leafroll. Maine Agric. Exp. Sta. Bul. 297. p. 37-52. 1921. See p. 44-45.....Potato spindle-tuber. Maine Agric. Exp. Sta. Bul. 312. p. 21-44. 1923. See p. 30-31. Schultz, E. S. and Folsom, Donald. Transmission, variation, and control of certain degeneration diseases of Irish potatoes. Jour. Agric. Res. 25: 43-117. 1923. See p. 93-94.

made for comparing triplicated plots of two new Green Mountain strains. Strain BA originated, as far as these tests are concerned, in a lot that was introduced into northeastern Maine in 1921. In that year it was healthy but it was grown close enough to diseased fields so that parts of the lot became contaminated and, as a result, in 1922 it contained about 3 per cent mosaic and about the same proportion of spindle-tuber in a part grown on Aroostook Farm (Field 7 of Table 4). Tubers apparently spindle-tuber were selected in 1922 as seed for spindle-tuber plots in a yield-rate test. As grown in 1923, the disease was in its third year. (In 1921 spindle-tuber was present in the last part of the season, but not evident then; in 1922 spindle-tuber, though evidently present, apparently did not hurt the yield rate in the affected hills, grown as they were from recently infected, good-looking tubers, as much as in diseased hills grown from spindle-shaped tubers; in 1923 the seed-tubers being spindle-shaped, obviously the final dead-level of complete disease had been reached.) The healthy part of this strain was grown in 1923 from good-shaped tubers of the 1922 crop.

The two lots of seed of strain BA, after having been disinfected in formaldehyde solution, were cut by one person into seed-pieces approximating and averaging one ounce. Without care in this regard, there is a tendency to cut smaller seed-pieces from spindle-tuber seed because of the greater number of eyes for a given weight of tuber. The seed was planted on June 2, which was late for a normal season but not for this one, in rows three feet apart, with a two-man planting machine, and was fertilized with 5-8-7 goods at the rate of about 1500 pounds an acre. Seven plots were planted, each of two rows about 250 feet long. Each plot therefore consisted of about one-thirtieth of an acre. The arrangement of diseased and healthy plots, numbered in order of planting and of location, is given in Table 1. Their appearance on July 9 is shown in Fig. 1, when the diseased rows were more spindling than the healthy. Their appearance on September 1 is shown in Fig. 2, where all rows look about alike. Actually there was an obvious difference in vine type. The percentage of mosaic found during the season averaged about 6 for the healthy plots and 8 for the diseased, and there was about the same proportion of spindle-tuber in the healthy plots. The crop was dug two weeks after the death of the plants resulting from

the frosts of September 14 and 20. The net weight of the yield from each plot was determined on a large platform scales by difference between the gross weight in barrels and the weight of the barrels. Knowing the number of hills, the size of each plot, and the yield, the yield rate in pounds per hill and in barrels[6] and bushels per acre was calculated and is given in Table 1, together with the averages.

TABLE 1.

Effect of spindle-tuber upon the yield rate in test plots, 1923.

Plot No.	Yield rate of healthy plots			Yield rate of diseased plots		
	Per hill	Per acre		Per hill	Per acre	
		Barrels	Bushels		Barrels	Bushels
	Pounds			Pounds		
1	1.93	147	404	----	----	----
2	----	----	----	1.51	107	295
3	1.88	145	399	----	----	----
4	----	----	----	1.53	115	317
5	1.90	140	385	----	----	----
6	----	----	----	1.63	114	315
7	1.98	140	385	----	----	----
Average	1.92	143	393	1.56	112	309

The yield rates given in Table 1 show that the disease in the spindle-tuber plots reduced the yield rate about 20 per cent in pounds per hill and in barrels or bushels per acre. Further loss resulted from the decrease in quality. Additional comparisons will be made later in connection with Table 3.

The second strain, mentioned previously, for our purposes may be called strain BV and may be considered as originating in a lot introduced into northeastern Maine in 1920. In that year it was healthy but, like strain BA, it became contaminated and in spite of being rogued had about 17 per cent mosaic and about 2 per cent spindle-tuber by 1922 (Field 6 of Table 4). A half-

[6] A "barrel" is 2¾ bushels or 165 pounds.

acre of this strain was rogued in 1922 and some mosaic hills were selected. The two parts, rogued and mosaic, were handled with the same procedure as has been described for the two parts of strain BA, except that smaller plots were planted, each about a hundred-and-fiftieth of an acre. Each plot was at the end, in the same rows, of the correspondingly numbered plot of strain BA. Knowing the number of total hills, of mosaic hills in the rogued or "healthy" plots, and the yield of the total and of the mosaic hills (staked and dug separately), the yield rates were calculated and are given in Table 2, together with the averages.

TABLE 2.

Effect of mosaic upon the yield rate in test plots, 1923.

Plot No.	Yield rate of healthy hills	Yield rate of "healthy" plots[1]			Yield rate of diseased hills in "healthy" plots	Yield rate of diseased plots		
		Per hill	Per acre			Per hill	Per acre	
			Barrels	Bushels			Barrels	Bushels
	Pounds	Pounds			Pounds	Pounds		
1	2.18	1.84	145	399	1.23	----	----	----
2	----	----	----	----	----	1.19	96	264
3	2.02	1.70	140	385	1.29	----	----	----
4	----	----	----	----	----	1.19	95	261
5	2.00	1.69	130	358	1.31	----	----	----
6	----	----	----	----	----	1.13	92	252
7	1.72[2]	1.54	123	339	1.37[2]	----	----	----
Average	1.98	1.69	135	370	1.30	1.17	94	259

[1]The "healthy" plots contained respectively 44, 49, 49, and 38 per cent mosaic hills as examined on July 20.

[2]In Plot 7 more hills were staked late in the season and dug afterwards as mosaic hills than were recorded as being present on July 20. Probably some healthy hills were included. This would explain the greater calculated yield rate per mosaic hill in this plot.

These yield rates show that in pounds per hill in comparison with the healthy hills, the yield rate was reduced 15 per cent by the presence of about 45 per cent mosaic, 35 per cent by mosaic appearing for the first season in the progeny of healthy plants, and 40 per cent by mosaic of two or more years' standing. Also, that in comparison with the half-mosaic plots, a complete mosaic condition reduced the yield rate per acre about 30 per cent. Ac-

TABLE 3.

Comparison of yield rates of Tables 1 and 2, giving difference between means and probable error of difference[1]; also ratio between difference and its probable error.

Means compared		Difference between means and P.E. of difference	Ratio between difference and P.E.
Table 1, healthy plots, pounds per hill—1.922±.019	Table 1, spindle-tuber plots, pounds per hill—1.557±.016	.365±.025	**14.6:1**
Table 1, healthy plots, barrels per acre—143.0±1.0	Table 1, spindle-tuber plots, barrels per acre—112.0±1.3	31.0±1.6	**19.4:1**
Table 1, healthy plots, bushels per acre—393.2±3.5	Table 1, spindle-tuber plots, bushels per acre—309.0±3.9	84.2±5.2	**16.2:1**
Table 2, healthy hills, pounds per hill—1.980±.056	Table 2, "healthy" plots[2], pounds per hill—1.692±.018	.288±.059	**4.9:1**
Table 2, healthy hills, pounds per hill—1.980±.056	Table 2, mosaic hills in "healthy" plots, pounds per hill—1.390±.017	.689±.059	**11.5:1**
Table 2, healthy hills, pounds per hill—1.980±.056	Table 2, mosaic plots, pounds per hill—1.170±.011	.819±.057	**14.2:1**
Table 2, "healthy" plots, pounds per hill—1.692±.018	Table 2, mosaic hills in "healthy" plots, pounds per hill—1.300±.017	.392±.025	**15.7:1**
Table 2, "healthy" plots, pounds per hill—1.692±.018	Table 2, mosaic plots, pounds per hill—1.170±.011	.522±.021	24.9:1
Table 2, "healthy" plots, barrels per acre—134.5±2.9	Table 2, mosaic plots, barrels per acre—94.3±1.2	40.2±3.1	13.0:1
Table 2, "healthy" plots, bushels per acre—370.2±8.1	Table 2, mosaic plots, bushels per acre—259.0±2.0	111.2±8.3	13.4:1
Table 2, mosaic hills in "healthy" plots, pounds per hill—1.300±.017	Table 2, mosaic plots, pounds per hill—1.170±.011	.130±.020	6.5:1
Table 1, healthy plots, pounds per hill—1.922±.019	Table 2, healthy hills, pounds per hill—1.980±.056	.058±.059	1:1
Table 1, healthy plots, barrels per acre—143.0±1.0	Table 2, "healthy" plots, barrels per acre—134.5±2.9	8.5±3.1	2.7:1
Table 1, healthy plots, bushels per acre—393.2±3.5	Table 2, "healthy" plots, bushels per acre—370.2±8.1	23.0±8.8	2.6:1

[1]Calculated as the square root of the sums of the squares of the probable errors of the means.

[2]The "healthy" plots contained from 38 to 49 per cent mosaic hills.

cording to this, in Green Mountains mosaic reduced the yield rate more than spindle-tuber. Over nine-tenths of the mosaic was of the mild type (Fig. 3).

Mention may be made here of a small test with Irish Cobblers also on Aroostook Farm in 1923, but in another field. The planting was done on the same date and in about the same way as for the Green Mountains. The crop was dug earlier, before the tops had been killed by frost and while many tops were still green. Two "healthy" rows, with about a fortieth acre in each, yielded at the rate of 91 and 103 barrels respectively (250 and 282 bushels) while a spindle-tuber row planted between them yielded at the rate of 55 barrels (152 bushels). The same strain was used for both parts. The "healthy" rows contained about 50 per cent spindle-tuber. In this test the greater percentage of spindle-tuber reduced the yield about 40 per cent.

Further comparisons are made in Table 3 by means of mathematical calculations which show that in the Green Mountains the differences in yield rate due to spindle-tuber and mosaic were much more significant than any differences due to the number of years of infection by mosaic, or than any differences in healthy stocks due to source of strain. The most significant difference was between the yield rates per acre of part mosaic and all mosaic stock. It is thus indicated that the greatest mistake possible for a grower is not so much in the choice between healthy strains as in the use of apparently healthy but contaminated stocks and in the continued use of stocks already showing disease.

EFFECT OF PROXIMITY AND ISOLATION UPON THE SPREAD OF DISEASE IN 1922.

In 1920 and 1921, as has been previously reported,[7] samples were taken from different parts of a half-dozen healthy fields. These indicated that "mosaic sometimes spreads very readily from diseased to adjacent healthy lots, that proximity and heavy aphid infestation together increased the spread of mosaic, and that with greater isolation.....it may be possible to maintain stock mosaic free if once the disease is eliminated." It may be added that

[7]Schultz, E. S., and Folsom, Donald. Transmission, variation, and control of certain degeneration diseases of Irish potatoes. Jour. Agric. Res. 25: 43-117. Pl. 1-15. See p. 109-110 and Table XXVIII.

aphids also were reported as transmitting mosaic and spindle-tuber.[8]

In 1922, thirty-five fields were sampled that were practically healthy or at least comparatively so. Each sample consisted of from 25 to 50 tubers taken from the same number of consecutive hills (that is, one tuber from each hill) either after the tops had been killed or not long before they were killed. The places from which the samples were taken varied, and depended upon the location of the nearest diseased field or fields. (Here a "field" is considered as being a continuous area planted with one strain of one variety.) For example, if the rows extended east to west and the rows on the north were diseased, the healthy samples were taken from the first healthy row on the north, next to the diseased stock, and in other rows at progressively greater distances from the diseased stocks. Or, if isolated somewhat from other fields, the samples might be taken from the near side, the middle, and the far side relative to the nearest diseased field. With these limitations, the place for each sample was selected at random, and the first tuber to be found in a hill was taken. The aphids were counted that were on five leaves selected at random from some plant at the soil, near the soil, at the middle, near the top, and at the top, respectively. These leaves did not necessarily come from the same plant.

The sacked and labeled samples were stored in a bin of the usual type until the next season, when they were planted by hand. The pieces from each tuber were planted in consecutive hills, each group or tuber-unit indicating whether or not the parent tuber had become diseased at the time of taking the sample in the preceding season. Two inspections were made for mosaic and one for spindle-tuber, the last being made after the tubers had become large enough for their shape to be ascertained. Knowing the number of total and diseased tuber-units in each sample, the percentage of mosaic and of spindle-tuber was calculated.

About 200 samples were thus gathered in the 35 healthy fields sampled in 1922, and were planted in 1923. The facts regarding these are summarized in Table 4. Table 5 gives the facts concerning the corresponding diseased fields and samples. The order in which the healthy fields are numbered in Table 4 has no special significance except that in general the numbering

[8] *Ibid.* See p. 50 and p. 60.

proceeds in the order of location, from the more southern to the more northern localities. The diseased stocks in Table 5, however, are numbered like the corresponding healthy fields, with letters added to the numbers to distingush diseased fields from the healthy ones and from each other. For example, the two diseased fields next to Field 4 of Table 4 are designated as Fields 4A and 4B in Table 5.

TABLE 4.

Description of healthy fields sampled in 1922.[1]

Field	Variety	Disease	Aphids on 5 leaves[2]	Samples[3]	Progeny, 1923			Remarks
					No. of tuber units	Mosaic	Spindle-tuber	
		%				%[4]	%[4]	
1	Green Mountain	Trace[5] mosaic, no spindle-tuber	16	Row N-1	30	0	3	
				Row N-5	29	0	0	
				Row N-10	30	0	0	
				Row N-20	30	3	0	
				Row N-40	29	0	0	
				Row N-70	30	0	0	
				Row N-130	29	0	0	
2	Green Mountain	Trace[5] mosaic, no spindle-tuber	55	Row S-1	27	0	11	Said to be from same source as for Field 1
				Row S-5	29	0	7	
				Row S-10	30	3	7	
				Row S-20	30	3	0	
				Row S-40	28	4	4	
				Row S-69	30	0	0	
3	Green Mountain	Trace[5] mosaic, no spindle-tuber	195	Row S-1	27	7	0	Said to be from same source as for Field 1. Total rows 35. Progeny of sample S-5 are 7 per cent leaf-roll, and of sample S-20, 3 per cent leaf-roll
				Row S-5	29	14	0	
				Row S-10	25	8	0	
				Row S-20	29	3	3	
				Row S-35	29	17	41	
4	Green Mountain	Trace[5] mosaic, no spindle-tuber	--	Row S-1	29	28	3	Said to be from same source as for Fields 1, 2, and 3. Total rows 148. Progeny of samples S-20 and N-10 are 3 per cent leaf-roll
				Row S-10	29	10	3	
				Row S-20	29	3	7	
				Row S-40	30	7	0	
				Row S-70	26	15	0	
				Row N-40	30	7	0	
				Row N-20	30	3	0	
				Row N-10	30	3	0	
				Row N-1	30	3	0	
5	Irish Cobbler	No mosaic, trace spindle-tuber	--	Row N-1	30	[6]	0	Same stock as for Field 35
				Row N-10	30	[6]	3	
				Row N-20	30	[6]	0	
				Row N-40	30	[6]	0	
				Row N-60	30	[6]	0	
				Row N-80	30	[6]	0	
				Row N-100	30	[6]	0	
6	Green Mountain	18 mosaic, rogued; 2 spindle-tuber	--	Row W-1, S. end	44	52	7	
				Row W-5, S. end	51	43	7	
				Row W-10, S. end	48	19	7	
				Row W-15, S. end	50	42	7	
				Row W-15, S. end to middle	47	43	7	
				Row W-15, middle	48	31	7	
				Row W-15, middle to N. end	48	19	3	
				Row W-15, N. end	48	48	0	
7	Green Mountain	3 mosaic, rogued; 5 spindle-tuber	--	Row E-11	50	10	2	
				Row E-40	50	4	6	
				Row E-70	46	7	9	
				Row E-100	48	6	8	

Description of healthy fields sampled in 1922.[1]—Continued.

Field	Variety	Disease	Aphids on 5 leaves[2]	Samples[3]	Progeny, 1923			Remarks
					No. of tuber units	Mosaic	Spindle-tuber	
		%				%[4]	%[4]	
8	Green Mountain	3 mosaic, 2 spindle-tuber	--	N.W. corner	50	16	8	Same stock as for Field 7
				Center	50	8	6	
				S.E. corner	50	4	2	
9	Green Mountain	No spindle-tuber[6]	--	Row S-1	29	10	3	Total rows 11.
				Row S-6	30	3	0	Same strain but
				Row N-2	21	0	0	not same stock as for Fields 7 and 8
10	Green Mountain	5 mosaic, no spindle-tuber	105[8]	Row N-1	30	7	0	
				Row N-5	26	11	0	
				Row N-10	30	13	0	
				Row N-20	30	10	3	
				Row N-40	31	3	0	
				Row N-80	32	9	0	
11	Green Mountain	12 mosaic, no spindle-tuber	--	Row S-1	28	29	14	
				Row S-5	30	17	0	
				Row S-10	30	20	0	
				Row S-20	30	30	0	
				Row S-40	30	37	0	
				Row S-60	30	3	0	
12	Green Mountain	Trace mosaic,[9] no spindle-tuber	112	Row N-1	30	0	0	
				Row N-5	29	7	0	
				Row N-10	30	3	0	
				Row N-20	29	7	0	
				Row N-50	30	3	0	
				Row N-110	30	21	0	
13	Green Mountain	Trace mosaic, trace spindle-tuber	--	Row E-3	29	0	0	Total Rows 43
				Row E-13	30	7	0	
				Row E-23	30	0	3	
				Row E-33	30	3	7	
14	Green Mountain	Mosaic rogued; 20 to 55 spindle-tuber	--	Row W-10, N. end	28	7	68	Length of rows 750 feet
				Row W-10, S. end	25	0	20	
				Row W-1, S. end	25	4	60	
15	Green Mountain	As for Field 13	--	Row E-1	30	7	3	Said to be from same source as for Field 13. Total rows 66
				Row E-5	29	0	0	
				Row E-15	30	0	0	
				Row E-32	30	0	3	
				Row W-15	29	0	0	
				Row W-5	30	0	0	
				Row W-1	30	7	0	
16	Green Mountain	5 mosaic, no spindle-tuber	130	Row W-1	28	14	0	Total rows 26
				Row W-5	30	10	3	
				Row W-10	30	7	0	
				Row E-10	30	3	0	
				Row E-5	29	17	3	
				Row E-1	30	7	3	
17	Green Mountain	2 mosaic, no spindle-tuber	20	Row E-5, S. end	30	13	0	Total rows 102
				Row E-50, S. end	29	17	0	
				Row W-5, S. end	35	14	0	
				Center	30	10	0	
				Middle W. side	30	13	3	
				Middle N. side	30	13	3	

Description of healthy fields sampled in 1922.[1]—Continued.

Field	Variety	Disease	Aphids on 5 leaves[2]	Samples[3]	Progeny, 1923			Remarks
					No. of tuber units	Mosaic	Spindle-tuber	
		%				%[4]	%[4]	
18	Green Mountain	2 mosaic, no spindle-tuber	--	S. end	26	12	4	Said to be from same source as for Field 17
				Center	31	7	0	
				N.W. corner	29	7	0	
19	Green Mountain	7 mosaic, no spindle-tuber	--	Row E-1	30	17	17	Total rows 33
				Row E-5	29	10	0	
				Row E-10	30	7	0	
				Row E-20	30	17	0	
				Row E-30	30	20	0	
20	Green Mountain	9 mosaic, no spindle-tuber	16	Row E-1, N. end	29	10	3	Total rows 56, 700 feet long
				Row E-5, N. end	30	13	0	
				Row E-10, N. end	30	17	0	
				Row E-20, N. end	29	10	0	
				Row E-30, N. end	30	3	0	
				Row E-50, N. end	30	3	0	
				Row E-20, S. end	30	3	0	
21	Green Mountain	1 mosaic, no spindle-tuber	20	Row N-1	30	3	3	Total rows 50
				Row N-5	30	13	0	
				Row N-10	29	7	3	
				Row N-25	29	3	0	
				Row S-10	30	3	0	
				Row S-5	30	0	0	
				Row S-1	31	3	0	
22	Green Mountain	3 mosaic, rogued; no spindle-tuber	38	Row E-1	30	7	10	Total rows 21
				Row E-5	28	18	0	
				Row E-10	30	7	0	
				Row E-20	28	0	14	
23	Irish Cobbler	5 spindle-tuber	--	Row S-1	31	6	16	Total rows 100
				Row S-5	31	6	6	
				Row S-10	30	6	13	
				Row S-19	33	6	6	
				Row S-50	31	6	7	
				Row N-40	27	6	11	
				Row N-20	29	6	7	
				Row N-10	30	6	17	
				Row N-5	29	6	17	
				Row N-1	29	6	14	
24	Green Mountain	2 mosaic, no spindle-tuber	170	S.E. corner	50	8	0	
				N.E. corner	50	6	0	
				Center	50	16	0	
				W. end	46	9	0	
25	Green Mountain	1 mosaic, trace spindle-tuber	40	Row E-1	28	7	43	Total rows 99
				Row E-5	29	24	55	
				Row E-10	29	24	30	
				Row E-20	30	30	50	
				Row E-50	29	10	17	
				Row W-20	26	23	15	
				Row W-10	30	20	0	
				Row W-5	30	13	47	
				Row W-1	25	60	64	
26	Green Mountain	3 mosaic, no spindle-tuber	75	N.W. corner	49	4	2	Second, third, and fourth samples 250, 1000, and 1700 feet respectively from N.W. corner
				N.W. center	50	6	0	
				S.E. center	50	4	0	
				E. end	36	3	0	

Description of healthy fields sampled in 1922.[1]—Concluded.

Field	Variety	Disease	Aphids on 5 leaves[2]	Samples[3]	Progeny. 1923			Remarks
					No. of tuber units	Mosaic	Spindle-tuber	
		%				%[4]	%[4]	
27	Green Mountain	Trace mosaic, trace spindle-tuber	--	Near side	43	2	2	Said to be from same source as for Fields 13 and 15
				Far side	48	0	0	
				Second Field	50	2	0	
				Third Field	50	0	2	
28	Green Mountain	Trace mosaic, trace spindle-tuber	--	E. end	44	7	0	Said to be from same source as for Fields 13 and 15
				W. end	49	2	0	
29	Green Mountain	Trace mosaic, trace spindle-tuber	175	Row N-1	18	33	17	Said to be from same source as for Fields 13 and 15. Total rows 51
				Row N-5	24	54	0	
				Row N-10	26	27	0	
				Row S-25	25	24	0	
				Row S-10	24	13	0	
				Row S-5	27	8	0	
				Row S-1	29	48	0	
30	Green Mountain	6 mosaic, no spindle-tuber	41	Row S-1	24	4	0	
				Row S-5	22	9	0	
				Row S-10	22	0	0	
				Row S-20	24	0	0	
				Row S-40	23	22	0	
31	Green Mountain	1 mosaic, no spindle-tuber	88	Row E-1	23	0	0	
				Row E-5	30	7	0	
				Row E-10	30	13	0	
				Row E-20	30	10	0	
				Row E-50	30	13	0	
				Row E-100	30	17	0	
32	Green Mountain	Trace spindle-tuber[5]	10	Row S-1	19	0	36	Total rows 78
				Row S-39	16	0	0	
				Row S-78	21	0	0	
33	Irish Cobbler	1 spindle-tuber	--	Row W-1	27	6	11	Total rows 140
				Row W-10	30	6	7	
				Row W-20	19	6	11	
				Row W-30	28	6	7	
				Row W-50	30	6	3	
				Row W-100	30	6	0	
				Row W-140	29	6	24	
34	Green Mountain	10 to 35 spindle-tuber[6] [11]	--	Row S-1	30	47	47	
				Row S-5	29	52	17	
				Row S-10	28	71	39	
				Row S-20	29	45	43	
				Row S-40	22	41	59	
				Row S-70	29	45	21	
				Row S-110	30	33	50	
35	Irish Cobbler	Trace spindle-tuber	--	Near side	50	6	0	Same stock as for Field 5
				Middle	50	6	0	
				Far side	50	6	0	

[1]For description of the corresponding diseased stocks see Table 5.

[2]Taken at random respectively from some plant at the soil, near the soil, at the middle, near the top, and at the top. Reference is made to the compound leaves and not to leaflets.

[3]Rows were numbered from north to south as N-1, N-2, etc., and from any other side in a corresponding fashion. Thus N-5 would mean the fifth row from the north side and S-1, E-1, or W-1 would mean the first row on the south, east, or west respectively.

[4]Based on number of tuber-units diseased. See text p.

[5]"Trace" indicates less than 1 per cent.

[6]Not examined for mosaic.

[7]Not examined for spindle-tuber.

[8]Mostly of a species typically distributed irregularly over a field.

[9]After having been rogued.

[10]Present but not counted.

[11]Samples said to be from the same stock were 5 per cent mosaic.

TABLE 5.

Description of diseased fields nearest to the healthy fields sampled in 1922.[1]

Field[2]	Variety	Position in relation to healthy stock	Disease	Aphids on 5 leaves[3]	Progeny, 1923			Remarks
					No. of tuber units	Mosaic	Spindle-tuber	
			%			%[4]	%[4]	
1-A	Irish Cobbler	Adjoining on N.	35 spindle-tuber	200	30	5	77	
2-A	Irish Cobbler	Adjoining on S.	30 spindle-tuber, trace leafroll	305	30	5	67	Total rows 11. Progeny 10 per cent leafroll
3-A	Irish Cobbler	Adjoining on S.	15 spindle-tuber	275	28	5	82	
4-A	Green Mountain	Adjoining on S.	50 mosaic, 15 spindle-tuber	58	32	97	22	Said to be from same source as for Field 4 except secured a year earlier
4-B	Green Mountain	20 feet N.	50 mosaic, 25 spindle-tuber	53	25	52	48	
5-A	Green Mountain	Adjoining on N.	50 mosaic, 3 spindle-tuber	16	31	92	19	
6-A	Green Mountain	Adjoining on W.	18 mosaic, 2 spindle-tuber	--	--	--	--	Same stock as for Field 6, but not rogued
6-B	[6]			186	--	--	--	
7-A	Irish Cobbler	200 feet E.	15 spindle-tuber	116	60	5	7	
8-A	Irish Cobbler	Over 700 feet S.E.	15 spindle-tuber	--	--	--	--	Same stock as for Field 7-A
8-B	Green Mountain	700 feet N.W.	Over 50 mosaic[7]	--	--	--	--	
9-A	Irish Cobbler	Adjoining on S.	10 spindle-tuber[5]	--	30	5	10	Same stock as for Fields 7-A and 8-A
9-B	Green Mountain	Adjoining on N.	2 spindle-tuber[5]	--	30	7	0	Same stock as for Fields 7 and 8
10-A	Spaulding Rose	Adjoining on N.	25 spindle-tuber	50	32	0	47	
11-A	Irish Cobbler	Adjoining on S.	70 spindle-tuber	1100[8]	36	5	92	
12-A	Green Mountain	Adjoining on N.	23 mosaic, 50 spindle-tuber	--	19	11	44	

Description of diseased fields nearest to the healthy fields sampled in 1922.[1]—Continued.

Field[2]	Variety	Position in relation to healthy stock	Disease	Aphids on 5 leaves[3]	Progeny, 1923			Remarks
					No. of tuber units	Mosaic	Spindle-tuber	
			%			%[4]	%[4]	
12-B	Spaulding Rose	N. of Field 12-A		--	15	0	100	
13-A	Green Mountain	Adjoining on E.	Mosaic rogued, 33 spindle-tuber	65	30	13	73	Total rows 7
13-B	Irish Cobbler	Adjoining on W.	15 spindle-tuber	66	--	--	--	Miscellaneous lots
14-A	Irish Cobbler	Adjoining on E.	15 spindle-tuber	66	--	--	--	Identical with Field 13-B
14-B	Green Mountain	Adjoining on N.	35 mosaic, trace spindle-tuber	--	25	36	4	
15-A	Green Mountain	Adjoining on E.	40 mosaic, 25 spindle-tuber	69	30	60	57	
15-B	Green Mountain	Adjoining on W.	5 mosaic, no spindle-tuber	160	23	4	0	
16-A	Green Mountain	Adjoining on W.	50 mosaic, 8 spindle-tuber	40	30	47	10	
16-B	Irish Cobbler	Adjoining on E.	12 spindle-tuber	90	30	5	30	
17-A	Green Mountain	Adjoining at S.E. corner	7 mosaic, no spindle-tuber	--	149	14	3	Identical with Field 19
17-B	Green Mountain	Adjoining Field 17-A on E.	94 mosaic, 27 spindle-tuber	65	29	100	53	Identical with Field 19-A
17-C	Green Mountain	W. beyond grass strip 80 feet wide	70 mosaic, 80 spindle-tuber	60	20	90	82	
17-D	Mostly Rurals	200 feet N.	35 spindle-tuber, and dwarfed[9]	221	20	10	10	
18-A	Mostly Rurals	25 feet S.	35 spindle-tuber, and dwarfed[9]	221	20	10	10	Identical with Field 17-D
18-B	Irish Cobbler	180 feet N.W.	15 spindle-tuber	--	--	5	7	
19-A	Green Mountain	Adjoining on E.	94 mosaic, 27 spindle-tuber	65	29	100	53	Identical with Field 17-B
19-B	Green Mountain	Adjoining on W.	2 mosaic, no spindle-tuber	20	184	13	1	Identical with Field 17

Description of diseased fields nearest to the healthy fields sampled in 1922.[1]—Continued.

Field[2]	Variety	Position in relation to healthy stock	Disease	Aphids on 5 leaves[3]	Progeny, 1923			Remarks
					No. of tuber units	Mosaic	Spindle-tuber	
						%[4] [5]	%[4]	
20-A	Irish Cobbler	Adjoining on E.	12 spindle-tuber	45	31		13	
20-B	Irish Cobbler	50 feet S.	42 spindle-tuber	99	29	[5]	34	
21-A	Irish Cobbler	Adjoining on N.	70 spindle-tuber	210	25	[5]	100	
21-B	Spaulding Rose	Adjoining on S.	25 spindle-tuber	40	29	0	47	
22-A	Irish Cobbler	Adjoining on E.	75 spindle-tuber[11]	59	25	[5]	68	
23-A	Green Mountain	Adjoining on S.	15 spindle-tuber[5]	51	39	74	23	
23-B	Spaulding Rose	Adjoining on N.	50 spindle-tuber	39	24	4	38	
24-A	Green Mountain	210 feet S.E.	90 mosaic, 10 spindle-tuber (in Irish Cobbler admixture)	--	--	[5]	7	
24-B	Irish Cobbler	400 feet N.E.	[12]	--	--	[5]	7	
25-A	Irish Cobbler	Adjoining on E.	15 spindle-tuber	163	30	[5]	57	Total rows 12
25-B	Mills Pride[13]	60 feet E. of Field 25-A	70 mosaic, 50 spindle-tuber	376[8]	--	[5]	7	Same stock as for Field 25-C
25-C	Mills Pride[13]	Adjoining on W.	70 mosaic, 50 spindle-tuber	25	26	96	90	Same stock as for Field 25-B
26-A	Spaulding Rose	150 feet N.W.	60 spindle-tuber	33	29	0	52	
27-A	Spaulding Rose	150 feet distant	50 spindle-tuber	190[8]	20	0	33	
28-A	Spaulding Rose	Adjoining on E.	32 spindle-tuber	--	25	0	44	
29-A	Green Mountain	Adjoining on N.	80 mosaic, 10 spindle-tuber	138	24	96	17	Same stock as for Field 29-B
29-B	Green Mountain	Adjoining on S.	80 mosaic, 10 spindle-tuber	40	25	96	24	Same stock as for Field 29-A

Description of diseased fields nearest to the healthy fields sampled in 1922.[1]—Concluded.

Field[2]	Variety	Position in relation to healthy stock	Disease		Progeny, 1923			Remarks
					No. of tuber units	Mosaic	Spindle-tuber	
				%		%[4]	%[4]	
30-A	Irish Cobbler	Adjoining on S.	15 spindle-tuber	38	16	[5]	19	
31-A	Irish Cobbler	Adjoining on E.	40 spindle-tuber	316	30	[5]	33	
32-A	Irish Cobbler	Adjoining on S.	50 spindle-tuber	[14]	22	0	59	Identical with Field 33-A
33-A	Irish Cobbler	Adjoining on W.	50 spindle-tuber	[14]	30	0	80	Identical with Field 32-A
33-B	Spaulding Rose	Adjoining on E.	40 spindle-tuber[5]	[14]	--	5	31	
34-A	Green Mountain	Adjoining on S.	98 mosaic,[15] 80 spindle-tuber	--	24	100	96	
35-A	Irish Cobbler	30 feet distant	25 spindle-tuber[5] [16]	--	20	5	45	Progeny 20 per cent leafroll

[1]For description of the healthy fields see Table 4.
[2]The Arabic number is the same as that of the healthy field involved.
[3]Taken at random respectively from some plant at the soil, near the soil, at the middle, near the top, and at the top. Reference is made to the compound leaves and not to leaflets.
[4]Based on number of tuber-units diseased.
[5]Not examined for mosaic.
[6]Miscellaneous diseased experimental plots, starting about 20 feet distant, and extending for 500 feet, to the north.
[7]Not examined for spindle-tuber.
[8]Mostly of a species typically distributed irregularly over a field.
[9]Few Green Mountains as mosaic admixture.
[10]75 per cent dwarfed and mosaic.
[11]Estimated from vines, not determined from tubers of sample taken.
[12]Spindle-tuber present; percentage unknown.
[13]Very similar to Green Mountains.
[14]Present but not counted.
[15]In preceding generation, 1921.
[16]Not examined for leafroll.

A study of the data in Tables 4 and 5 discloses several kinds of results from growing healthy stock next to diseased. It also shows that the problem is not simple, but that it has many phases. These can be considered one at a time.

Date of digging samples. The writers have pointed out in a previous paper[9] that digging tubers before the tops are dead may reduce the percentage of disease in the tubers by anticipating both some inoculation by aphids and some diffusion of the virus from the inoculated leaves down into the tubers. Samples should not be taken until after the tops are dead, if the maximum infection is to be obtained, or if the samples are to represent the seed as dug by the grower. However, in order to get a large number of samples it is necessary to start getting them before digging is begun by the growers. In 1922, the healthy Green Mountain samples were dug September 8 to 14. The samples in each series from a given field were dug on the same day and so are comparable. Sometimes it was necessary to dig the Irish Cobbler samples before the Green Mountains. Wherever this difference would have importance in the following discussion, the dates of digging will be given.

Most spread to nearest single row. In Field 1, the first row of healthy Green Mountains next to spindle-tuber Irish Cobblers contracted a small percentage of spindle-tuber while the fifth and following rows did not. The same disease spread in the same manner from diseased Green Mountains to healthy Green Mountains in Field 9 and Field 20, and, with a larger percentage of disease, also in Fields 11, 19, and 29 (north side). In Field 32, spindle-tuber was contracted by 36 per cent of the Green Mountain healthy plants in the row next to diseased Irish Cobblers while the thirty-ninth row remained healthy. In Field 33, spindle-tuber was contracted by 24 per cent of the Irish Cobbler plants in the row (W-140) next to diseased Spaulding Rose, while the fortieth row remained healthy. In Field 2, the first, tenth, and fortieth rows of healthy Green Mountains contracted respectively 11, 7, and 4 per cent spindle-tuber from diseased Irish Cobblers. In Field 25, the first, fifth, and tenth rows (west side) contracted respectively 64, 47, and 0 per cent spindle-tuber from Mills Pride, a variety very similar to Green Mountains. (See Fig. 4 for the fifth and tenth row samples.) Mosaic spread to the first row and

[9] *Ibid.* See p. 97 and 104.

not to the fifth row on each side of Field 15, going from Green Mountains to Green Mountains. In Field 4, the first, tenth, and twentieth rows of healthy Green Mountains contracted respectively 28, 10, and 3 per cent mosaic from diseased Green Mountains.

Most spread to nearest group of rows. Spindle-tuber spread from diseased Green Mountains to the first 20 rows of healthy Green Mountains but not to the fortieth row and beyond, in Field 4. Spindle-tuber spread from Irish Cobblers to Green Mountains in the first 5 rows but not to the tenth row, in Field 16 (east side); in the first 10 rows but not to the twenty-fifth, in Field 21 (north side); in the first 50 rows but not to the hundredth, in Field 33 (west side). On the south side of Field 29, the first row of healthy Green Mountains contracted six times as much mosaic as the fifth row, while from the north side there is a steady decrease from the first five rows to the forty-sixth row from the north.

Most disease increase in farthest rows. Although many fields have been mentioned wherein greater proximity to diseased stock resulted in greater contraction of the disease, there are a few cases where the opposite is true. In Field 3, spindle-tuber was in only 15 per cent of the diseased Irish Cobblers; it spread within the Cobblers so that 82 per cent of the progeny were spindle-tuber; it did not spread to the first 10 rows of the adjacent Green Mountains but was in 41 per cent of the progeny of the thirty-fifth row. The last row was next to a "fence-row" of bushes and trees, and across the road from the Cobblers was a large clump of rose bushes. It seems possible that aphids of the type that overwinters on rose bushes[10] invaded the Cobbler field early, caused much transmission from hill to hill, and when migrating further were stopped by the hedge, settled down on the last rows of Mountains, and infected them. In presenting this explanation the writers also have in mind the possibility of weeds harboring potato diseases and of other insects in addition to aphids being able to transmit mosaic and spindle-tuber. However, the early infestation of potatoes by aphids near to rose bushes and the accumulation of migrating aphids at the edge of a potato field next to woody vegetation, have been observed while the other possibili-

[10]Patch, Edith M. Rose bushes in relation to potato culture. Maine Agric. Exp. Sta. Bul. 303. p. 321-344. 1921.

ties have not yet been demonstrated for Maine conditions. In Fields 12 and 30 the various samples show much variation, but in each case there is some question as to the extent and uniformity of roguing, which was done by the grower.

Spread to both nearest and farthest rows. In Field 22, spindle-tuber spread from diseased Irish Cobblers to the first row of healthy Green Mountains and also to the twentieth row (the next to the last row), but not to the tubers dug in the fifth and tenth rows. This case may belong to those in the following section.

Light, irregular spread or increase. The small percentage of spindle-tuber in the twentieth row of the healthy Green Mountains of Field 10, with none in the first ten rows, seems attributable to spread from the diseased Spaulding Rose adjoining. In Fields 2 and 16, a small percentage of spindle-tuber spread to some rows beyond rows that remained healthy. The question of the agent of spread will be considered later. In Fields 5, 13, 15, and 27, the presence originally of a trace of spindle-tuber in the healthy stock makes it as probable for the increase to have resulted from hill-to-hill spread as from row-to-row or field-to-field spread. The same is true of mosaic in Fields 1, 2, 13, 14 and 27.

General spread or increase. In Field 34, spindle-tuber was present in from 10 to 35 per cent of the hills in different parts of the "healthy" field and was present in from 17 to 59 per cent of the progeny. Such an increase is to be attributed to hill-to-hill spread even though there was an adjacent spindle-tuber field where the tops died down early, thus favoring the dispersal of insects. On the other hand, the general increase of spindle-tuber in Field 25 from a trace in 1922 to from 0 to 64 per cent in 1923, is apparently due to spread from the diseased fields grown on both sides in 1922. The same explanation seems to apply regarding mosaic in this field. The general increase of spindle-tuber in Field 23 and of mosaic in Field 3, Field 4 (north part), Fields 6, 7, 8, 10, 11, 12, 16, 17, 18, 19, 20, 21, 22, 24, 26, 28, 31 and 34, is probably due wholly or in large part to the presence of mosaic in 1922 and to consequent hill-to-hill spread within the field.

No spread. Spindle-tuber apparently did not spread from adjoining diseased to healthy stocks in Fields 12, 28, 29 (south side), 30, 31, and 35, these stocks remaining free from the dis-

ease in the progeny grown in 1923. Only one Green Mountain stock remained free from mosaic in 1923. This was from Field 32, grown next to Irish Cobblers apparently free from mosaic. Field 26 showed very little increase in mosaic.

Field-to-field spread compared with hill-to-hill spread. The great diversity of conditions makes it difficult and hardly profitable to compare the hill-to-hill spread, as shown by the increase in disease from 1922 to 1923 in "healthy" and diseased stocks, with the field-to-field or row-to-row spread. The possibilities are shown by the following examples. In Field 4 (south side), there was considerable spread of mosaic to the first row and also considerable increase of mosaic in the diseased stock (from 50 to 97 per cent). In Field 30 there was no spread of spindle-tuber to the healthy stock and very little increase in the diseased stock (from 15 to 19 per cent); the latter was dug two weeks earlier. In Field 32 there was considerable spread of spindle-tuber to the first row but not much increase in the diseased stock nearby (50 to 59 per cent). In Field 29 (south side) there was no spread of spindle-tuber although the increase in the diseased stock was from 10 to 24 per cent.

Spread of mosaic compared with spread of spindle-tuber. Comparison of these two diseases regarding field-to-field spread can be made profitably only when the two diseases are about equally abundant in the diseased field and when the healthy field is of the Green Mountain variety. Such conditions hold for only one field. Field 25-C was 70 per cent mosaic and 50 per cent spindle-tuber, and contaminated Field 25 (west side) about equally with the two diseases. Comparison of the two diseases regarding hill-to-hill spread can be made profitably only when the two diseases are about equally prevalent (or equally rare) in a Green Mountain field. Such conditions hold for five fields. In Field 25-C, mentioned just previously, mosaic increased from 70 to 96 per cent and spindle-tuber from 50 to 90 per cent. In Field 27, a trace of each increased very little. In Fields 7 and 8, each disease increased about the same from a small percentage; here mosaic was rogued in at least the former field while spindle-tuber was not. It may be pointed out that in Field 4-B mosaic showed little increase from 50 per cent while spindle-tuber nearly doubled from 25 per cent.

Direction of spread. In Field 21, spindle-tuber spread somewhat from the diseased field on the north side but not from the one on the south side; here the former was much more diseased and was of a variety that matured earlier, thus inducing earlier dispersal of insects. In Field 29, where 51 rows of healthy stock were planted between two parts of the same diseased stock, the spread southward from the diseased stock on the north side was much more pronounced, although the hill-to-hill spread was no greater on the north side. In this connection it may be pointed out that in Field 8 the hill-to-hill spread of both mosaic and spindle-tuber was greater from the south-east to the north-west. An explanation for this is suggested by the fact that in 1923 in the same field, planted with similar stock, the writers found an increasing degree of infestation of aphids from the south-east to the north-west, indicating what may have occurred in 1922.

Effect of isolation. Most of the healthy fields sampled in 1922 were grown next to diseased fields. Some were isolated from the nearest diseased fields by intervening grassland or crops other than potatoes. None happened to be isolated from diseased fields by other healthy fields of potatoes, but the effect of such isolation can be judged from the effect of intervening rows of the same healthy stock. Spindle-tuber apparently did not spread from Field 4-B to Field 4 (north side), over a 20-foot interval of fence-row, or from Field 35-A to Field 35 over a 30-foot interval of fence-row, or from Fields 24-A and 24-B to Field 24 over a distance of from 210 to 400 feet. Spindle-tuber did spread to Field 18 separated from Field 18-A (on the south) by 25 feet of roadway; to Field 17 separated from Field 17-C (on the west) by 80 feet of grassland and separated from Field 17-D (on the north) by 200 feet of grassland; and to Field 26 separated from Field 26-A (on the north-west) by 150 feet of hayland. The mosaic increase in Fields 4 (north side) and 24, mentioned previously in this paragraph in relation to spindle-tuber, is probably due to hill-to-hill spread. Field 8, though showing more mosaic and more spindle-tuber toward the north-west corner which was about 700 feet distant from a diseased field, is discussed above in connection with the direction of spread.

Parts of one strain in different places. Data from the growers, with no contrary evidence, indicated that at least five Green Mountain strains and one of Irish Cobblers were planted each in

two or more of the fields sampled in 1922. Strain BA, one used in the yield-rate tests described previously, was planted in Fields 7, 8, 9-B and 9. In Fields 7, 8, and 9-B planted from the same stock, it behaved about the same, while in Field 9, introduced from the same grower a year later, it showed somewhat less disease. Strain BV, also used in the yield-rate tests, was planted in Fields 6 and 34. It showed much more spindle-tuber in Field 34, following proximity to diseased stock in 1921, than in Field 6, following isolation in 1921. Strain C was planted in Fields 1, 2, 3, and 4. It became contaminated with spindle-tuber in proximity to diseased stocks in Fields 1, 2, and 4, and with mosaic in proximity to diseased stocks only in Field 4 (south side). Strain J was planted in Fields 13, 15, 27, 28, and 29. Although it became contaminated with spindle-tuber and mosaic to some extent in Fields 13 and 15, and showed a slight increase in Fields 27 and 28, in these fields disease did not increase nearly as much as in Field 29. Strain T was planted in Fields 17 and 18 and became slightly contaminated with spindle-tuber and showed a hill-to-hill spread of mosaic. Strain BC, Irish Cobblers, was planted in Fields 5 and 35, and remained practically healthy.

Harboring of mosaic by Irish Cobblers. Mosaic is usually rare in fields of the Irish Cobbler variety. Experiments conducted by the writers[11] have shown that a given disease may not have the same symptoms in different varieties. Mosaic, usually plainly shown by Green Mountains, may be masked in other varieties. Therefore proximity of Green Mountains to apparently mosaic-free fields of other varieties would not necessarily be harmless, since the other fields might be diseased without showing any of the effects usually thought of as being associated with mosaic. So it is of interest to determine the effects of proximity of Green Mountains to fields of Irish Cobblers and Spaulding Rose that were supposedly free from mosaic. No spread resulted from such proximity in Fields 1, 2, 27, and 32. In Fields 3, 9, 22, and 28 possibly some of the increase in mosaic is due to spread from the adjacent fields. (See discussion above on "General spread or increase.")

Partly diseased tuber-units. When a comparatively small amount of disease is spread to healthy hills, the writers often have found that some tubers are only partly diseased and conse-

[11] *Ibid.* See p. 76.

quently produce tuber-units (groups of sister-hills) containing both healthy and diseased plants.[12] Sometimes instead of some parts of the tuber being healthy and other parts diseased, incompleteness of infection results in all the seed-pieces producing plants that first appear healthy when other tuber-units are completely and obviously diseased, and that later become diseased in the middle or upper parts. Both the partial infection of tubers and the delayed appearance of symptoms are important difficulties in any attempt to rogue a seed-plot early and completely. In 1923 a record was kept of the number of tuber-units, in these samples, that were only partly diseased. The samples listed in Table 4 were represented by 6148 tuber-units of which 663 were mosaic and 353 were spindle-tuber. Of the 663 mosaic tuber-units, 55 or about 8 per cent were only partly diseased. Of the 353 spindle-tuber tuber-units, 6 or about 2 per cent were only partly diseased. One is shown in Figure 5. The samples listed in Table 5 were represented by 1520 tuber-units of which 296 were mosaic and 519 were spindle-tuber. Of the 296 mosaic tuber-units, 1 or 0.3 per cent was partly healthy. Of the 519 spindle-tuber tuber-units, 3 or 0.6 per cent were partly healthy. The samples listed in Table 5 were from diseased fields so that much of the disease apparent in 1923 had been contracted before 1922 and had had time to become thoroughly established throughout the plants and tubers of 1922. Also the new infection contracted in 1922 would be more complete because of the presence of more disease in the field. Consequently the percentage of partly diseased tuber-units was smaller than in the samples from healthy fields.

Number of aphids counted. It would be interesting to try to correlate the number of aphids with the rate of spread of mosaic and spindle-tuber. However, in view of the paucity of aphid counts, the most that can be said is that aphids were generally present. The 16 aphid counts listed in Table 4 average 81, and the 37 counts in Table 5 average 139. From these averages for five-leaf samples[13] it is estimated that the average for each hill (with at least ten such series of five-leaf samples available) was probably about a thousand aphids. In view of the proof that

[12] *Ibid.* See p. 97.

[13] Reference is made to the compound leaves, not to leaflets.

one or two aphids can transmit mosaic to a small potato plant[14], a thousand aphids per hill might be expected to result in considerable spread. However, many of the aphids feeding upon potatoes are not winged, many of the winged (that is, wing-bearing) aphids are the fall migrants that are seeking other plants than potatoes, aphids usually are not so frequent until rather late in the season, and plants are harder to infect when larger. Therefore more facts are necessary than those got in 1922, if the amount of spread in each field is to be estimated accurately during the same season. It may be added here that in Ireland the transmission of one potato degeneration disease (leafroll) has been demonstrated by means of other insects in addition to aphids (leafhoppers, capsid bugs, and flea beetles).[15]

General Conclusions

In many fields listed in Table 5, the potato yield was reduced by the presence of a degeneration disease in every second or third hill grown. In the section of this bulletin upon the effect of degeneration diseases upon the yield rate in 1923, which apparently was a year very favorable for good growth by diseased hills as well as by healthy ones, it was shown that mild mosaic and spindle-tuber, the two most common degeneration diseases in northeastern Maine, reduced the yield rate of infected hills to the extent of 20, 30, or 40 per cent depending upon the disease and variety. Using the figure 30 per cent as the average reduction, with a third of the hills in a field diseased, the conclusion follows that in such a field ten per cent of the gross yield per acre is lost through degeneration diseases. This is disregarding the effect of spindle-tuber on quality. In other words, nine acres planted with disease-free seed would give the same gross yield as ten acres planted with seed such as is often now grown. This is important from the viewpoint of those who think that future progress will come from increased profit and yield-rate per acre rather than from increased total acreage and yield per farm.

[14] *Ibid.* See p. 83-84.

[15] Murphy, Paul A. Investigations on the leaf-roll and mosaic diseases of the potato. Journ. Dept. Agri. Ireland 23:20-34. 1923.....On the cause of rolling in potato foliage; and on some further insect carriers of the leaf-roll disease. Scien. Proc. Royal Dublin Soc. 17 n.s.:163-184. 1923.

Such fields, with a third of the hills diseased, are neither the best nor the worst. It should also be stated that they often present a good appearance to a superficial observer.

In the section of this bulletin upon the effect of proximity and isolation on the spread of disease in 1922, it was shown that the chances are favorable for contamination if healthy stocks are planted close to diseased fields. It is true that planting in such proximity is not always followed by a spread of disease, that often only a few rows are affected, and that with disease already present the hill-to-hill spread usually overshadows the field-to-field spread. However, it is not possible yet to be sure in any set of conditions whether or not mosaic and spindle-tuber are spreading, how far they are spreading, or what percentage of the crop is being infected. If a grower wants to follow the safest course toward obtaining disease-free seed he will make sure that the field in which it is grown is practically free from mosaic and spindle-tuber and is not close to any field that is diseased.

It is an old practice to "shift seed" when one's stock becomes obviously inferior, but such shifting to new seed has not helped as much as it should now with the fundamental reasons better understood. It is better to select new seed in the year when the old stock threatens to "run out" than to wait until the next year when it has run out and a heavy loss is the result. In selecting new seed it is better to determine the percentage of mosaic and spindle-tuber in the field and to estimate the probable increase than to judge only from the yield rate or general appearance in the bin. To avoid spindle-tuber it is better to use the field-run crop of a disease-free field than the best shaped tubers from a field with a high percentage of hills diseased. (This statement based on experimental tests was confirmed practically by two large-scale growers in 1922 and 1923.) For seed it is better to select a field that is isolated than one adjoining a diseased field. If it is thought necessary to use seed from a field planted next to diseased stock (and most seed-stocks have been so planted) it is often better to discard the outside rows or groups of rows than to use the whole stock.

Finally, it seems probable that experience will disclose that certain farms and growers have greater success than others in producing healthy seed. One stock grown on the same farm for

the third successive year in 1923 (Table 4, Field 27) was still better than seed freshly imported from the same original source. It was practically healthy, while another part of the same stock grown on another farm (Table 4, Field 29) became badly diseased in 1922. This points to the specialization of certain farms and growers in the production of foundation stock for home use in the region concerned.

FIG. 1. Test of effect of spindle-tuber on the yield rate of Green Mountains. On right, two rows marked "H" are healthy (Plot 3 of Table 1) and on left, two rows marked "S" are spindle-tuber (Plot 4 of Table 1). Further to the right are Plots 2 (spindle-tuber) and 1 (healthy). Further to the left are Plots 5 (healthy) and 6 (spindle-tuber). Each plot contains two rows. Photographed on July 9, 1923. Compare with Fig. 2.

FIG. 2. Test of effect of spindle-tuber on the yield rate of Green Mountains. The six staked rows, from right to left, are of Plots 4 (spindle-tuber), 5 (healthy), and 6 (spindle-tuber) of Table 1. Photographed on September 1, 1922. Compare with Fig. 1.

FIG. 3. Green Mountain hills photographed in northeastern Maine on June 29, 1922. On right, mild mosaic; on left, healthy. No spindle-tuber apparent in either up to and including the time of digging.

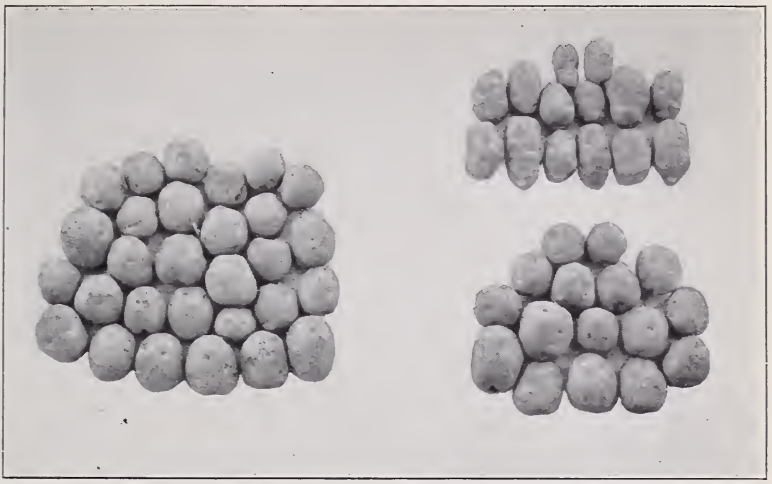

FIG. 4. On right, from sample taken from the fifth healthy row distant from spindle-tuber stock. On left, from sample taken from the tenth healthy row. Respectively rows W-5 and W-10 of Field 25, Table 4. Each tuber here represents one tuber-unit grown from the seed from one sampled hill. About half (upper group) of the right-hand sample is spindle-tuber.

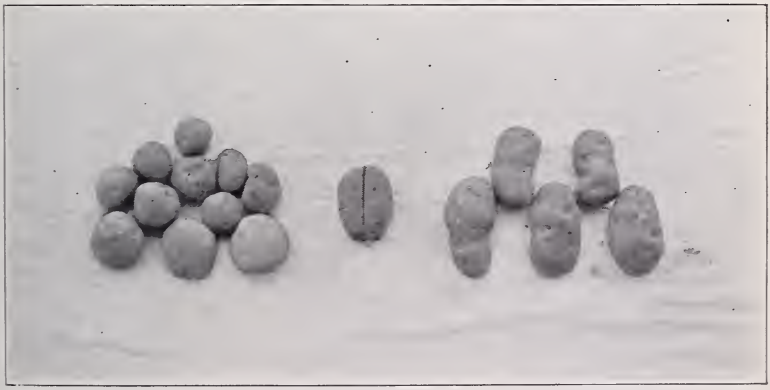

FIG. 5. Two hills, on right and left respectively, grown from the two halves of the seed-tuber shown. Photographed August 30, 1923. The two hills were grown adjacent to each other, but only one-half of the tuber had become infected with spindle-tuber.

The following bulletins will be mailed to any address, on request, as long as the supply lasts. They are published in limited editions and are mailed regularly to libraries and to other institutions in exchange. They represent types of publications which are not sent to the general mailing lists in the State.

Bulletin 314.

STUDIES ON MILK CONFORMATION IN RELATION TO MILK PRODUCING CAPACITY IN CATTLE. III. Conformation and Milk Yield in the Light of the Personal Equation of the Dairy Cattle Judge. Bulletin 314 gives the results of an attempt to ascertain from 2000 score cards on Jersey cattle the points in conformation on which emphasis is put by judges able to place their cattle most nearly in order of milk yield, by the cows' conformation. Eighteen points of conformation including the head, body, udder, teats, milk veins, general appearance, etc. are studied for the nineteen different judges. The results lead to such conclusions as the following,—"the good judge in contrast to the poor judge is able to place his cows more nearly in the relative order of milk yield by the total score; fore udder; udder broad and level; rear udder; tail; body wedged shape with deep large paunch. These are the points of conformation where the good judge displays his greatest skill. He is skillful in other points but not to the same degree."

Bulletin 315.

ABSTRACTS OF PAPERS NOT INCLUDED IN BULLETINS, FINANCES, METEOROLOGY, INDEX. This publication contains abstracts of papers, mostly of a technical nature, published by different members of the Station staff in various scientific journals. It also contains a statement of the income and disbursements of the Station during the year, the annual summary of the meteorological records made at the University and an index and table of contents of the Annual Report of the Station. The bulletins of the year are paged consecutively and taken together with the series of publications known as Official Inspections constitute the annual report. Therefore Bulletin 315 is chiefly of value to those who wish to maintain and bind a complete file of the Station bulletins for the year, with index and table of contents.

Bulletin 317.

THE BUCKTHORN APHID. This bulletin contains an account of a small greenish aphid that overwinters on the buckthorn *(Rhamnus)* in the egg stage. The first spring generation develops on the buckthorn leaves, distorting them. Later winged generations disperse to seventy or more different species of plants which the aphids infest during the summer. The bulletin gives the life history of the aphid; a list of all its known foodplants, many of which are of economic importance; a record of the habits of the species which is a pest in vegetable and flower gardens; a report of its role as a carrier of plant disease; and suggestions for control.